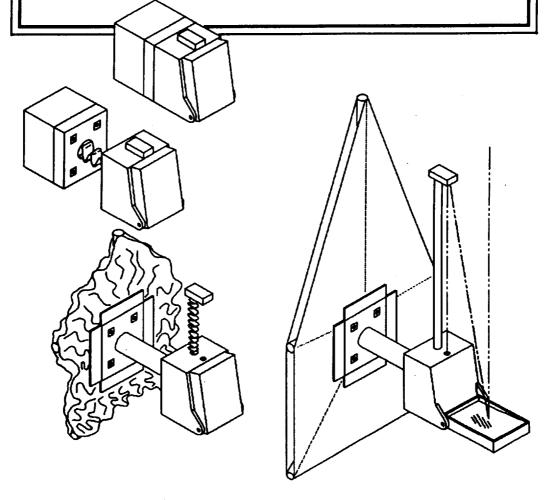
New Millenium Inflatable Structures Technology



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Ralph Mollerick
Mechanical Engineering Branch, Code 722
NASA/GSFC

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New Millennium Inflatable Structures Technology

General Applicability To New Millennium Missions

Inflatable structures technology offers the potential for significant reduction in spacecraft/ instrument mass and cost, reduced-volume conformal packaging, decreased complexity and increased deployment reliability. These capability improvements combined with the need to do more with less due to budget limitations mean that inflatable structures is an enabling or enhancing technology for numerous 21st century missions. The following Table lists some specific applications where inflatable technology can enable or enhance future space missions:

Inflatable Technology Application	Subsystem Applicability	Mission Applicability
Lightweight solar array substructure	Power GenerationPropulsion (electric)	All
Lightweight solar array concentrator	Power GenerationPropulsion (electric)	All (especially missions >1AU from sun)
Lightweight RF communications antenna	Communication	All (especially missions >1AU from sun)
Lightweight radiometer antenna	• Instrument Systems	Earth and Planetary Science
Lightweight radiotelescope antenna	• Instrument Systems	Astrophysics
Large lightweight deployable booms and other structural elements	• Spacecraft and Instrument Structures	All
Large optics substructure	●Communication (optical com) •Instrument Systems	Astrophysics
Large optical elements	●Communication (optical com) ●Instrument Systems	Astrophysics
Solar sails	• Propulsion	High energy missions
Solar thruster concentrator	Power Generation	High energy missions
Large lightweight shields for aerocapture	• Propulsion	Planetary
Large lightweight sunshades and sunshields	Thermal Management	Astrophysics

For some missions, multifunctional inflatable structures offer even greater mass and stowed volume reduction. One example of a multifunction inflatable structure is the addition of solar cells (or amorphous photovoltaic coatings) to a sunshield, radiotelescope antenna, or other large area inflated surface. Another example is a combination RF antenna and solar concentrator where the power collection and communication functions are time shared.

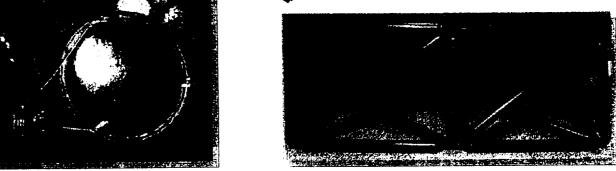
Specific Applicability To Large Aperture Infra-Red Astronomy Missions

The Next Generation Space Telescope (NGST) is a large aperture, diffraction-limited, passively cooled, near-IR (1-5 μ m) telescope. Compared to the Hubble Space Telescope, NGST is expected to provide ten times the aperture area for one-fifth of the mass and one-eighth of the cost. These requirements translate into a low-cost observatory with a deployed size that will not fit within the launch vehicles currently available, and mass limited to achieve travel to its Lagrange (L-2) point operational orbit. Inflatable structures technology offers the potential for achieving these small stowed volume and low mass requirements. The figure on the next page depicts the full range of uses for inflatable technology for NGST and other similar observatories.

Large aperture infra-red astronomy is not feasible without the combination of a favorable environment for the observatory, such as a halo orbit around L-2, and a highly effective thermal sunshield de-coupling the observatory from solar radiation. One of the enhanced technologies for NGST is application of an inflatable structure to serve as the telescope's sunshield. The uniqueness of the application allows the sunshield, which is conceptually the size of a tennis court, to be folded into a compact package on the spacecraft. Upon reaching orbit, the sunshield deploys into its final shape through a pressurizing and rigidizing process. The controlled inflation process would have to deploy the sunshield without interfering with other systems of the NGST observatory.

The technology requires a fraction of the packaging volume for stowing the sunshield, and less than half the weight compared to conventional methods using truss stiffeners, with many folding, rotating and actuating mechanisms for achieving a rigid and locked deployment configuration. One technique for the inflatable process utilizes a pressure source, such as nitrogen, reinforced kapton and aluminum foil which serve as the inflatable tubes, and valving for sequencing the controlled pressurizing process to yielding the aluminum laminate. Other inflatable techniques are available, such as the foam injection, gelatin, UV cure, or cold set, but these could pose contamination concerns.

Current technology does not exist to fashion a sunshield of the size needed for the NGST mission. NGST will require a sunshield of approximately 200 square meters. By contrast, the Cosmic Background Explorer (COBE) had one of the largest high performance solar shields ever flown. Its solar shield was approximately 10 square meters in area. NGST weight constraints require that the sunshield will have to weigh less than what the COBE solar shield weighed.



IAE Inflatable RF Antenna

Solar Array Concentrator

Solar Array Substructure

Sunshield

COM Antenna

Inflatable 3-D Truss

Application Of Inflatable Technology To NGST

Performance Requirements

High performance infra-red astronomy missions are dependent on three major requirements. The first is that the observatory is well removed from the Earth's interference. The Earth is a significant source of infra-red energy, and any IR observatory within its environment will be severely constrained in its observations, and will have to mitigate the IR noise received from the planet. The second requirement is that the collecting system for the instrument be as cold as possible. System sensitivity in the IR wavelengths is directly affected by detector temperature, and by temperature of its optics and receiver. The third requirement is to maximize collection area of the observatory. More collection area means more photons to count. Potential users of this technology other than NGST is the ExNPS program of JPL, the follow-on mission to the Far Infra-Red Space Telescope of ESA, and the International Space Station. Any mission that requires a light-weight thermal shield, such as the shuttle payloads during transfer orbit to the space station, will benefit from this technology.

Why the Technology Improvement?

The desire to meet cost constraints places more emphasis for lighter payloads with smaller launch vehicles. Launch vehicles that place several thousand kilograms of scientific instruments into low earth orbit, can place only 25 percent of that mass into an L-2 halo orbit, or maybe 30 percent into a 1 AU solar orbit. The use of larger launch vehicles cannot support the costs due to shrinking budgets for new programs. Weight conservation for IR telescopes require that passively achieve operational temperature (<60K) without using stored cryogen. A large, highly insulative sunshield is required to passively cool to cryogenic temperatures and allows significantly more observatory life than stored cryogen. The NGST sunshield will have to be about twenty times larger in projected area than the largest previously flown shield, have less than half the mass per square meter of what is currently state-of-the-art in deployable shields, and perform at least as well as current shield technology. Inflatable technology can be developed to exceed all of these requirements for an economical cost.

Space Flight Validation & Risk Reduction

Codes for modeling inflatable structures have not matured sufficiently to be used as tools for validating the hardware. Consequently, flight testing is essential to validate the technology and provide empirical data for modeling codes. Only flight testing can provide the combination of zero-g and vacuum environment to fully characterize the deployment dynamics, deployment shape control, and post-deployment (rigidized) structural characteristics of inflatable structures. Test effects, in the presence of ambient one-g conditions, gravity or air-damping forces, can overwhelm the deployment forces, making ground correlation testing and model validation of minimal use.

Maturity of Technology

The technology of inflatable structures was first used in space applications in the early 1960's for the Echo balloon communication satellites. In more recent years, inflatable technology has been used by the military for target decoys. The past applications differ from current and future

applications in three key ways. Firstly, the past applications have had relatively simple shapes and have not been precision structures, i.e., tightly controlled requirements on surface shape and size. Secondly, the past applications have not been used in functional elements as part of larger overall systems, and have not required the associated structural, thermal, or other subsystem performance requirements. Thirdly, deployment dynamics and shape control of past applications was not a concern as it is likely to be for future applications, i.e., NGST. The potential for inflatable structures will mature to large-sized antennas, radiometers, interferometers, radar, solar sails, solar concentrators, and sunshields.

The Spartan-207 Inflatable Antenna Experiment (IAE) flown on the STS-77 mission of May 19, 1996, is the most recent application of inflatable technology. Its objectives were to demonstrate that a 14-meter (46-ft) diameter antenna can be stored into a compact volume, and be deployed on orbit to validate the inflatable antenna's performance by measuring the characteristics of the reflector surface under varying conditions of internal pressure and solar aspect angle.

From the Spartan/IAE mission, several surprises were observed. The lenticular-shaped antenna supported by a torus and three struts failed to fully inflate as predicted. Internal residual pressure prior to deployment, was an order of magnitude greater than expected, which contributed to premature deployment. Shape control deployment was not accurately predicted, partially because of the residual initial pressure, and in part due to stored strain-energy within the material folds. The pressurizing process created undesirable shapes while undergoing inflation, and failed to reach the intended lenticular shape.

In considering inflatable structures for space application, the technology will need development in five main areas in order to achieve maturity. These areas are: analytical tools, material-rigidization processes, deployment dynamics control, fabrication techniques, and system testing.

Analytical Tools

Inflatable structures for aerospace designs will rely heavily on analytical tools in deriving structurally sound concepts, and performing optimizations using compatible codes. It will be important for existing specialized codes, such as the Finite Element Analysis of Inflatable Membranes (FAIM), IMOS, TRASYS and others, to work as an integrated multidisciplinary analytical tool, electronically sharing the data, and be tailored for performing analytical simulations. These tools will serve to predict shape controlled deployments, strength and dynamic characterization, and with capability to perform mass property determinations. The need for predicting inflatable structural performance requires development of analytical tools with validated flight data. A demonstration flight will be required with a fully instrumented inflatable structure for providing the initial data base, to include: pressure-strain energy, pressure time history, damping, mode- and mode-shape, and thermal characterization. Data will be compared with pre-flight predictions. The data base must include material properties developed from ground testing and be performance test validated with a demonstration flight. As analytical tools become available and supplemented with data from instrumented flights, greater confidence in performance and predictability can be established for inflatable flight structures.

Material-Rigidization Process

For inflatable structures to gain wide use, it will be necessary for the designer to tailor their mechanical properties to a specific application, or for there to exist a range of materials and supporting data base from which to choose. Most applications will desire high specific stiffness. Some applications will require very low CTE, while other applications will require specific RF or optical properties. The choice of materials for use in an inflatable structure is closely linked to the rigidization process employed. Aluminum laminate material, like that used on IAE, is deployed and rigidified through pressure alone. However, metal laminate materials may not always be suitable where low CTE is required. The use of carbon fiber or other composite materials that offer low CTE require both pressurization to achieve the deployed configuration and a separate rigidization process. Rigidization processes developed include foam injection, gelatin dry-out, UV-cure, and cold set. There are many combinations of materials and rigidization processes possible that require study, development and characterization before they can be applied. Other areas requiring research include contamination issues, joint design, storage life, and coatings to provide thermal, optical or RF properties. Each of these areas will require assessment for compatibility with folding techniques of the base material into compact shapes. The development of a material-rigidization processes and data base for aerospace application is a basic requirement necessary for widespread usage of inflatable technology.

Deployment Dynamics Control

Deployment dynamics for future inflatable structures fall into two generalized categories: shapes with precision surface figure, and shape controlled structures complying with "stay-out" zone boundaries. The former technology will require a decade of development before lenticular surfaces reach precision performance. The latter shapes will develop sooner and offer reasonably good predictions, provided that shape control deployment technology is developed. In addition to shape control, features such as surface flatness and specularity, will be properties required for missions such as the NGST sunshield.

Successful deployment of inflatable structures will be dependent on predicting performance and performing prototype testing. To the extent practical, ground testing must establish an understanding of effects due to residual gas and strain energy from material folds. These effects on deployment can be controlled by development of shape control technology. Applications where "stay-out" zone restrictions apply, hybrid solutions, such as bi-stem technology, may be used with the deployment scenario.

Rigidizing techniques must be evaluated for long-term performance. The most promising methods are the gelatin and aluminum laminate processes. The gelatin is a material that hardens with loss of entrained water at a controlled rate. A favorable property of the gel process is its ability to be reversed with addition of moisture, permitting restoration to the original stowed shape for ground testing. On the down side, release of water vapor becomes a source of contamination. The pressurizing of aluminum tube laminates is a one-shot process. Thin-wall tube theory is well known with stress-strain predictions within today's capability. It is not a reversible process, and therefore, deployment testing is limited to the non-flight article.

Fabrication Techniques

The inflatable structure technology will require significant investments into facilities and material processing. For the most part, the technology has the potential to achieve configurations and sizes that are typically not compatible with aerospace ground facilities. Processing of materials will make huge demands on how it is handled, shape formed, and enhanced for thermal capability, as well as how it conforms to optical characteristics, and meets structural stored and deployed performance requirements.

Techniques for handling gore segments and inflatable tubes will require floor areas that are both clean and large to accommodate the assembling and folding procedures. Programmable CNC equipment will be needed for producing tailor ready material into final shape processing. Bonding and seaming shapes into the final assembly may require robotic assistance.

System Testing

Large inflatable structures are difficult to test on ground. The facilities that are required tend to be large, and handling thin membrane structures makes this a challenging technology. The inflation and rigidizing process will require zero-g-assist facilities. These may be in the form of a water flotation bed, or g-negated from an overhead supporting system, i.e., balloons.

The proof of concept will require that there be methodology for demonstrating that inflatable structures can be fabricated with repeatability. Engineering test units (ETU) will be utilized for establishing consistency in stowing and deploying the inflatable hardware. The most suitable inflation technique must be established and tested. The rigidizing processes must be evaluated and demonstrated as a system for performance characterization. Controlled shape deployment and verification will present one of the more challenging design aspects for the technology. It may require that a micogravity and vacuum environment be necessary to perform measurements to confirm deployment dynamics, stability, and dimensional requirements.

Ground testing must be utilized to the fullest in order to minimize costs. ETU's can be used to verify material performance and thermal characterization. Materials can be evaluated in chambers for conforming to contamination requirements. Folded materials can be evaluated for deployment friction, and tested for life under UV simulation. Effects of prolonged stowage and ease of deployment must be characterized. For full performance verification, it will require an instrumented demonstration flight to assess the inflatable technology. The NGST mission has recognized the need for several demonstration flights, with the first flight to demonstrate the performance of the inflatable sunshield. These flights are scheduled for low earth orbits and will serve as decision-making milestone events.